University of BRISTOL

Bristol Composites Institute (ACCIS)

ADVANCED COMPOSITES COLLABORATION FOR INNOVATION & SCIENCE

On the role of localised post-buckling equilibria in axially compressed cylinders

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ROYAL ACADEMY OF ENGINEERING

EPSRC
Engineering and Physical Sciences Research Council

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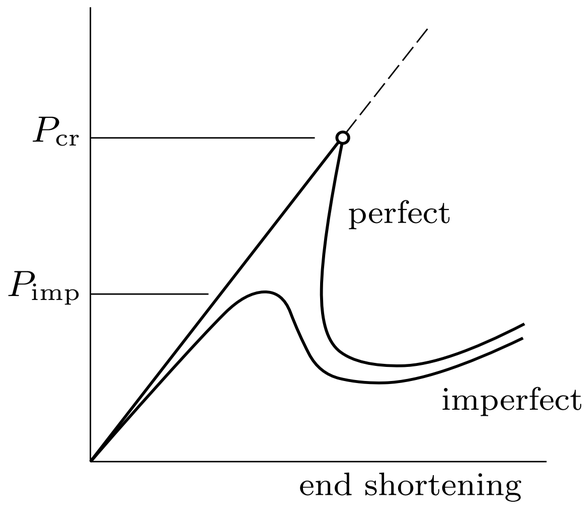
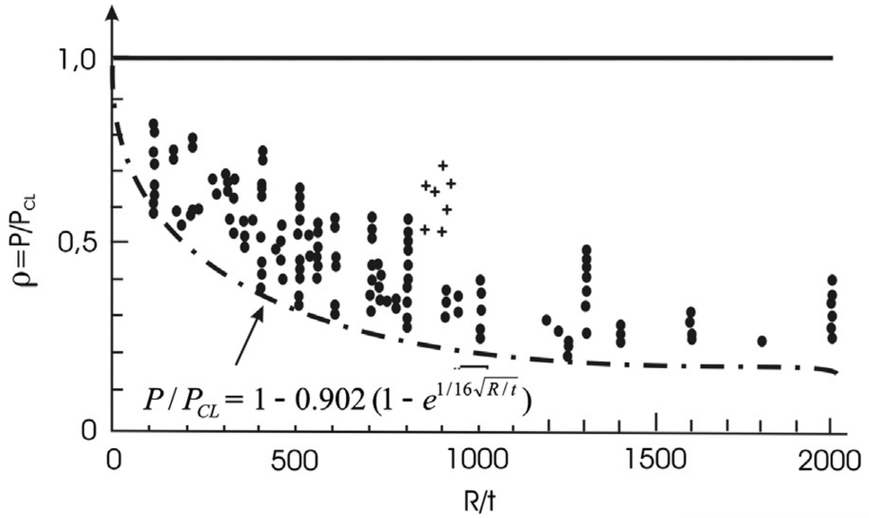
Motivation

- Cylinder buckling governed by a subcritical bifurcation
  - leads to imperfection sensitivity
- Empirical (safe) design threshold, *e.g.* NASA SP-8007
  - too conservative for modern manufacturing methods
  - difficult for small satellite launchers
- Need less conservative knockdown factors





Small satellite launchers *e.g.* Skyrora, Scotland

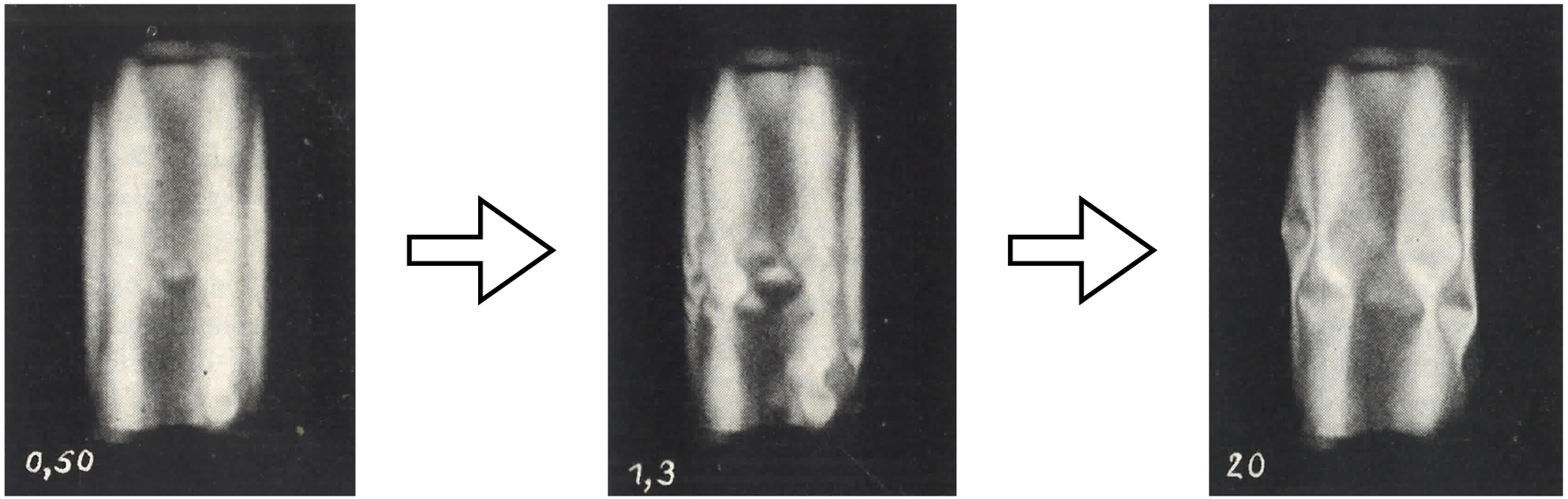
Smaller launchers are less efficient

Need less conservative knockdown factors

Approach

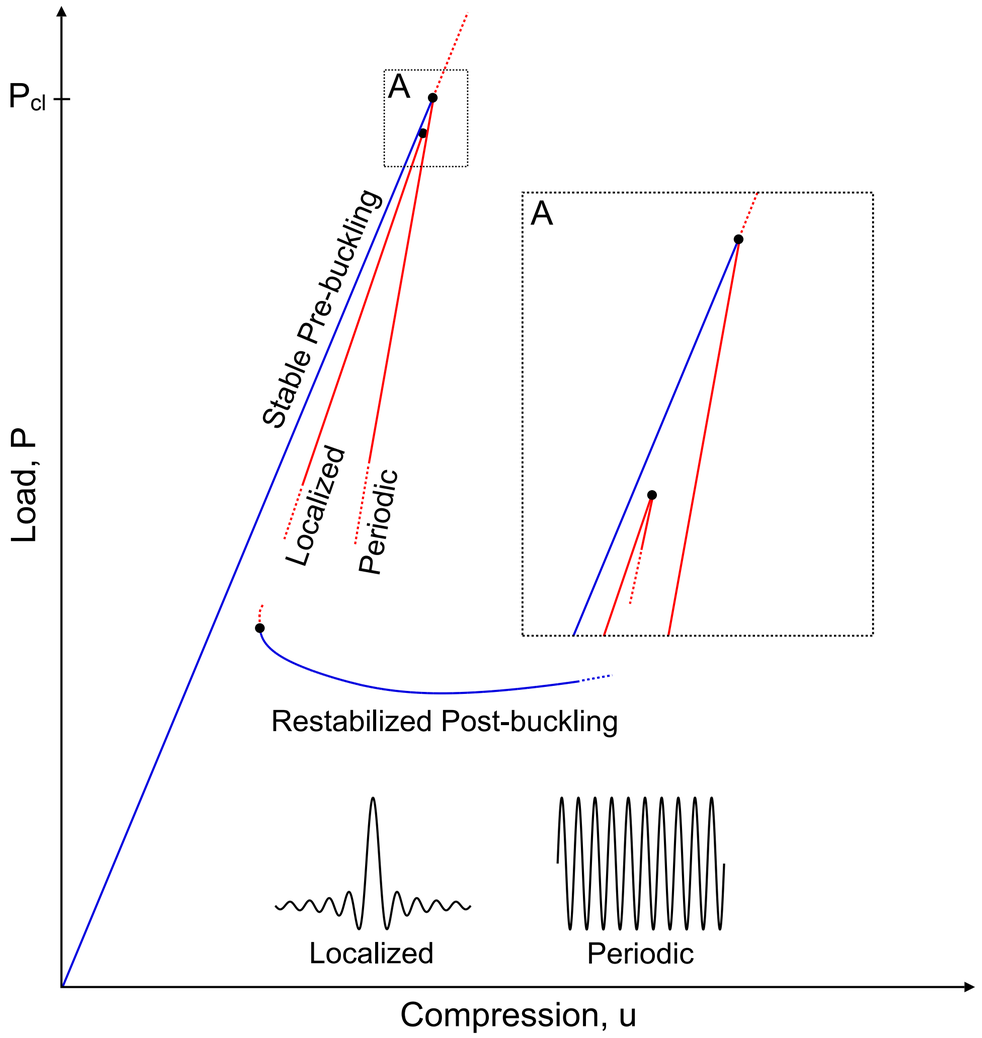
1. Study the equilibrium path of the buckling mode observed (most commonly) in experiments—the single dimple
2. Describe the deformation patterns that emerge as compression is varied
3. Derive a buckling threshold based on the level of compression for which the single dimple exists as an edge state

Eßlinger & Geier (1972)

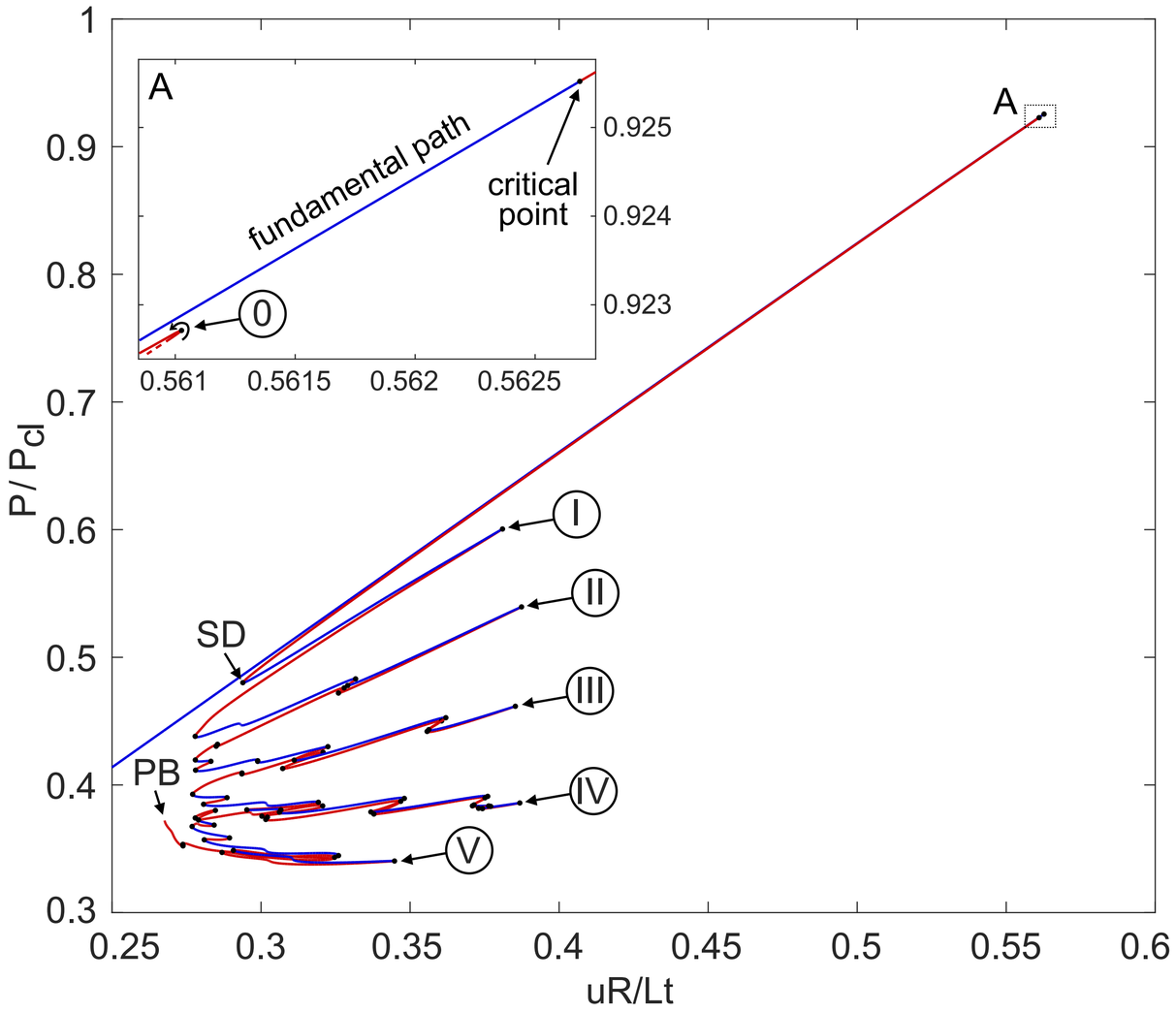


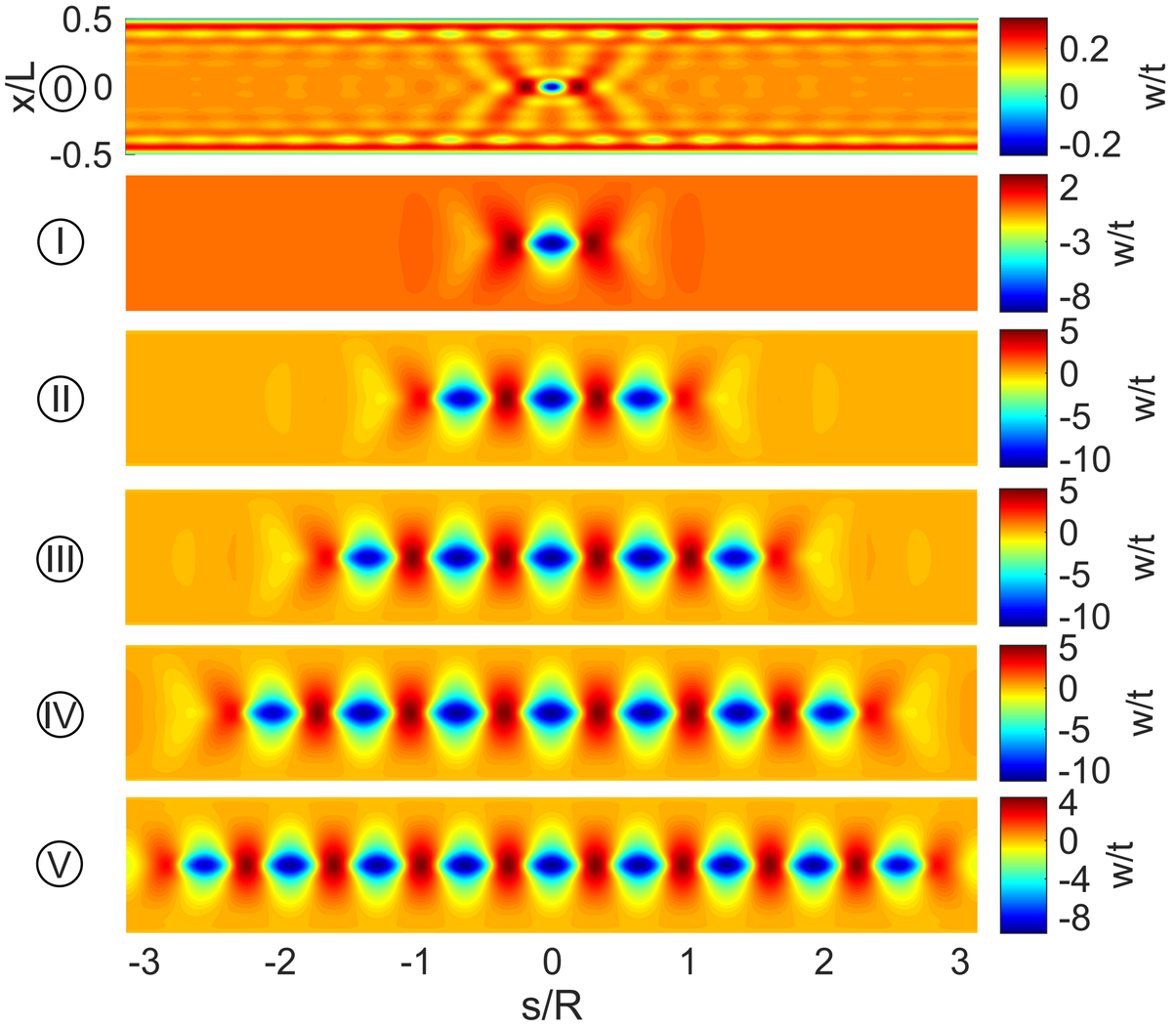
Generalised Path-Following

- "Riks" path-following with additional capabilities:
  - equilibrium is stable or unstable
  - pinpoint **critical points**
  - branch switch at bifurcation points
  - track critical points with other parameters
- Run Yamaki's (1984) longest cylinder:
  - R = 100 mm, L = 160.9 mm, t = 0.247 mm
  - E = 5.56 GPa (Mylar), ν = 0.3
  - Both ends clamped + axial compression
  - Quarter model using nonlinear finite elements with large rotations

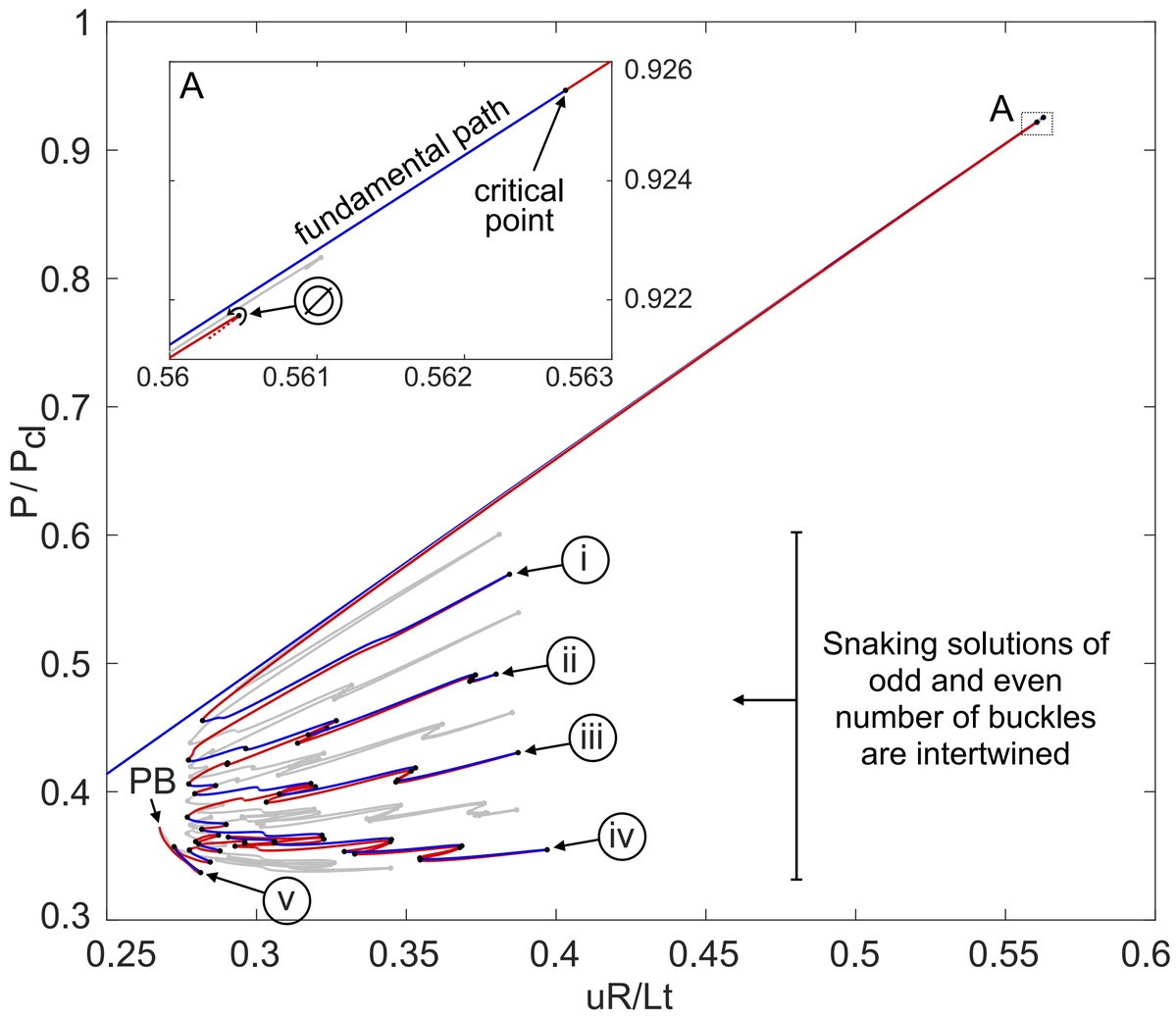


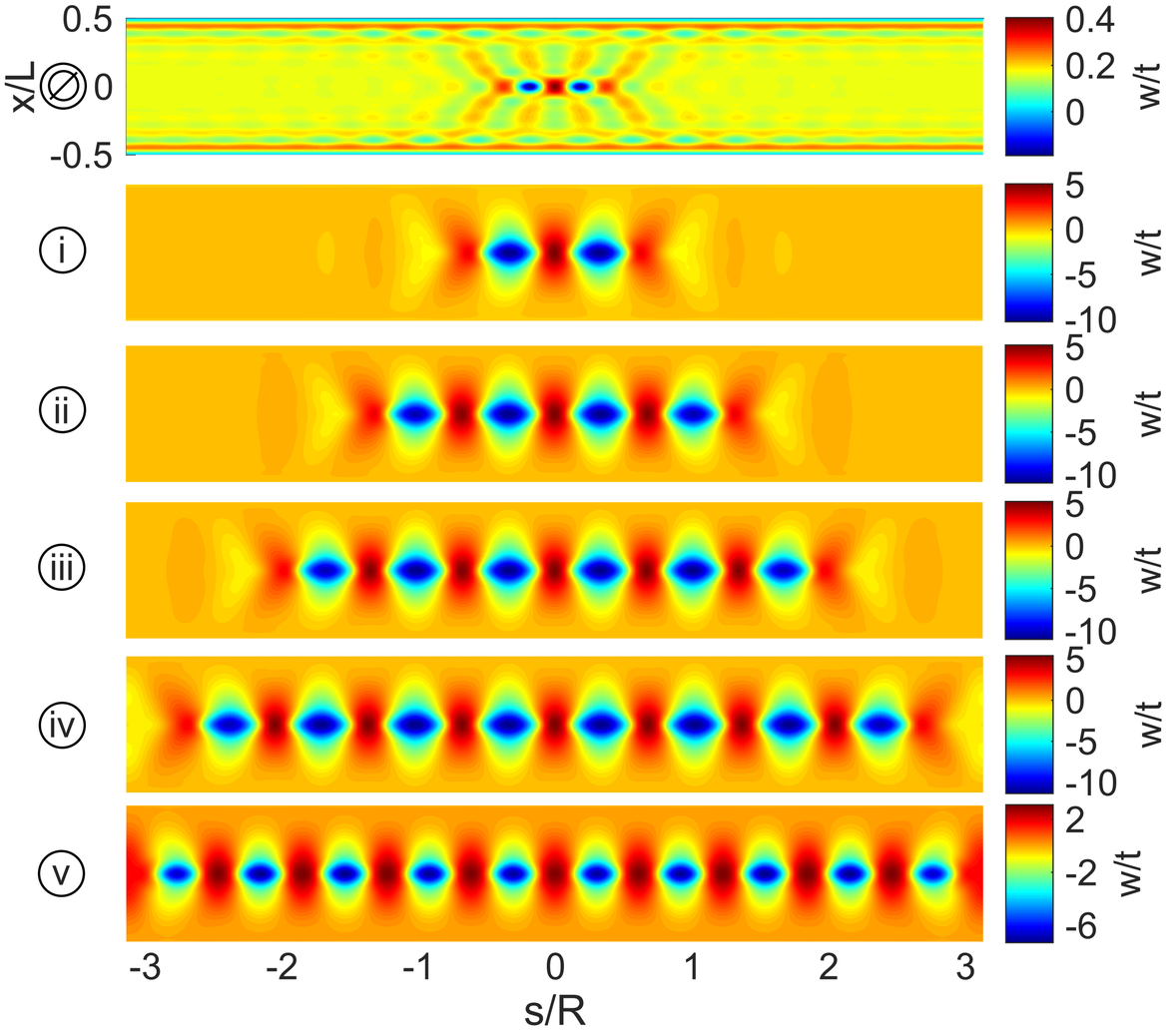
Single-dimple Snaking — Odd Nr Buckles



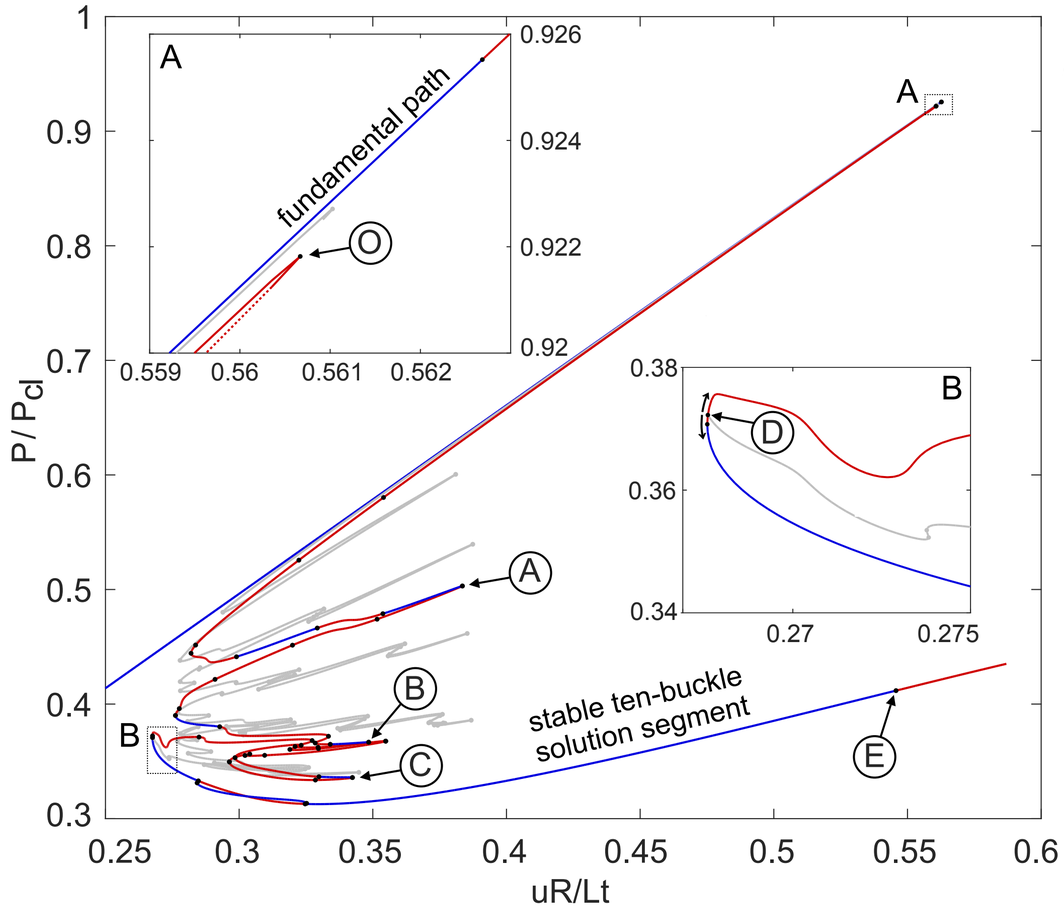


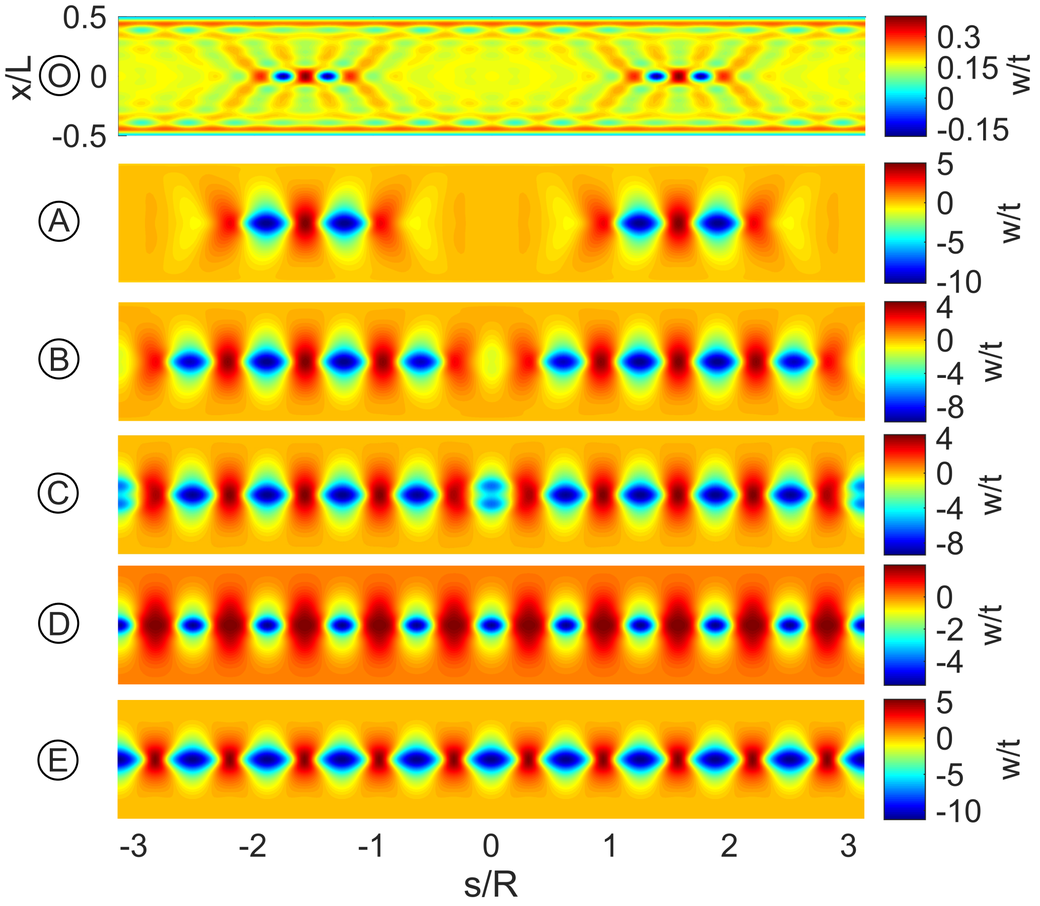
Single-dimple Snaking — Even Nr Buckles



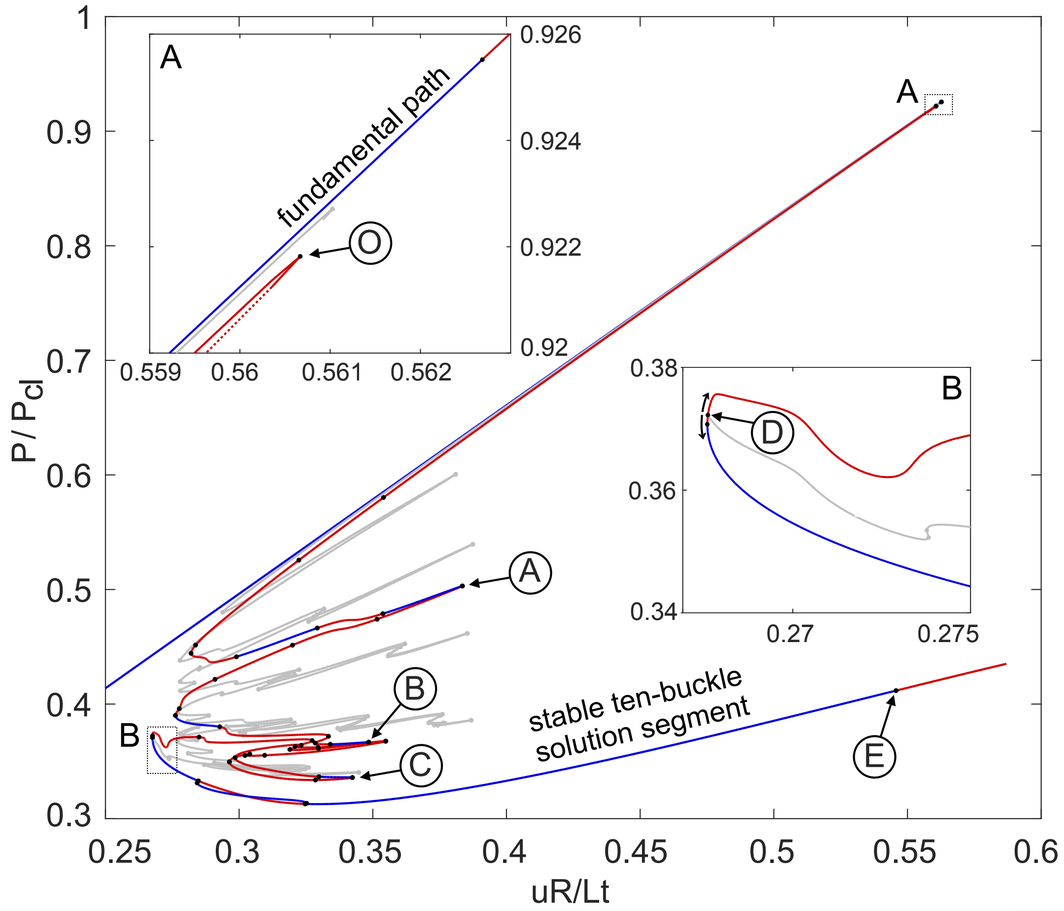


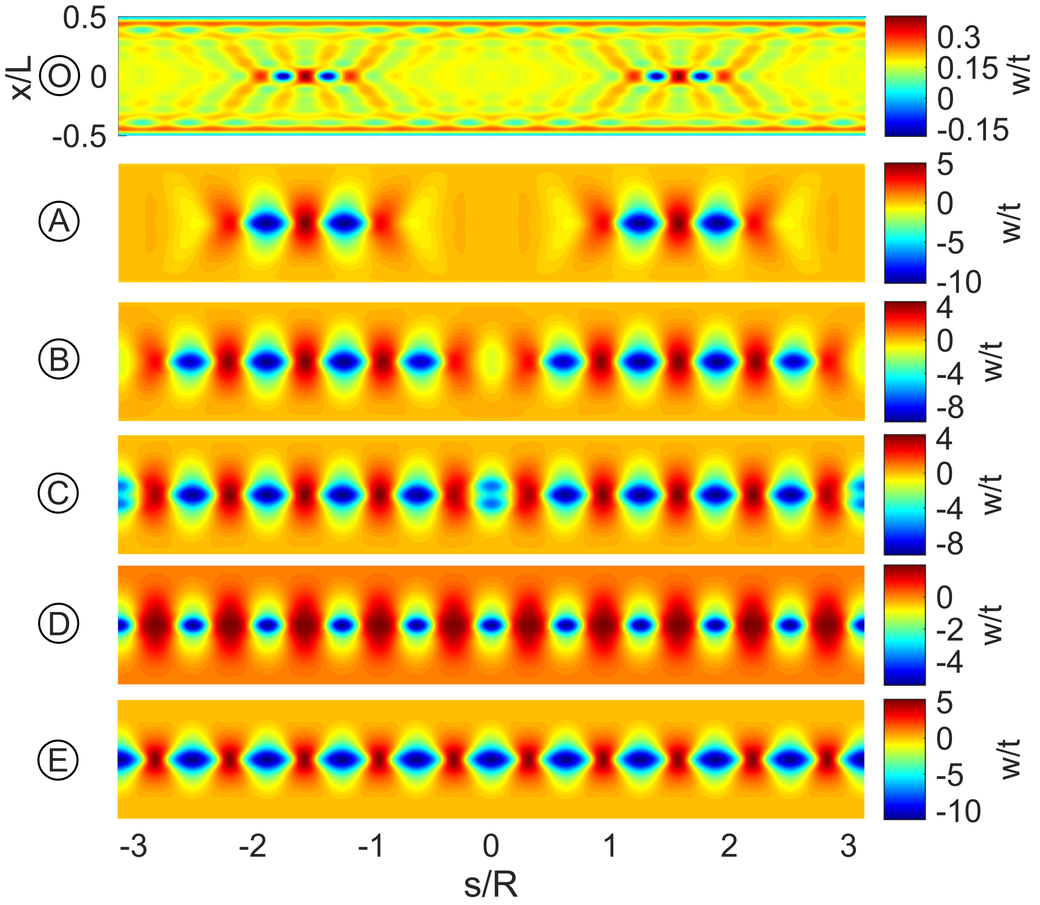
Four-dimple Snaking



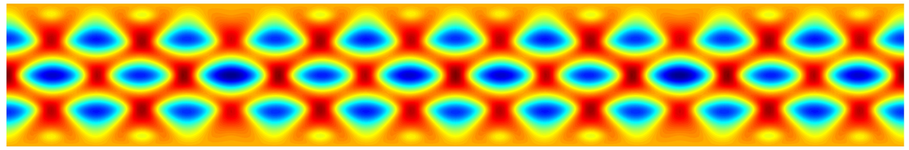


Four-dimple Snaking



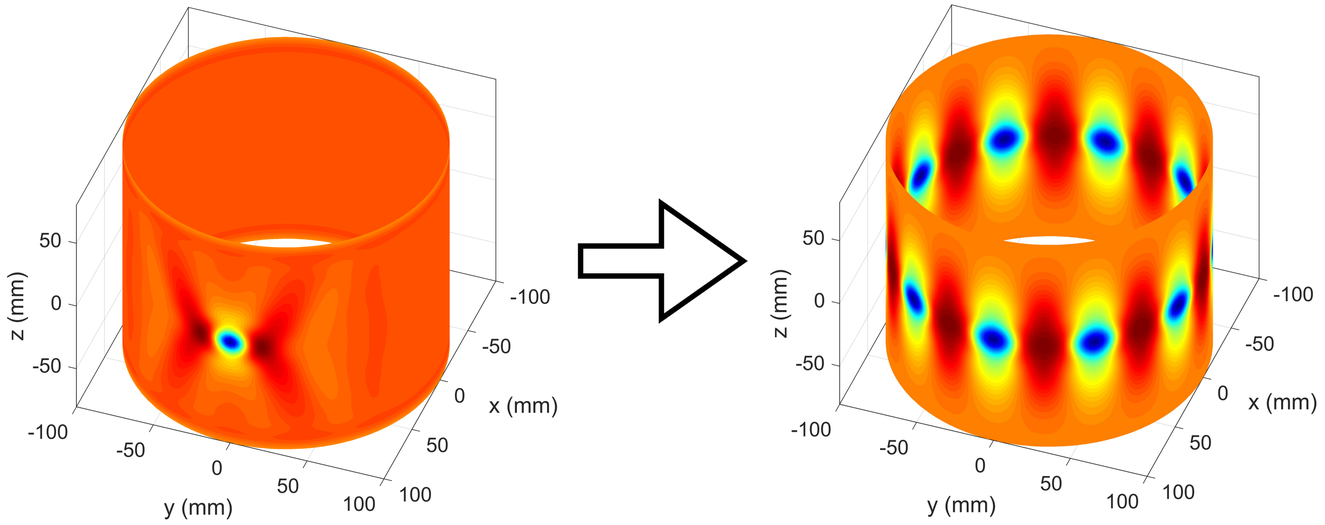


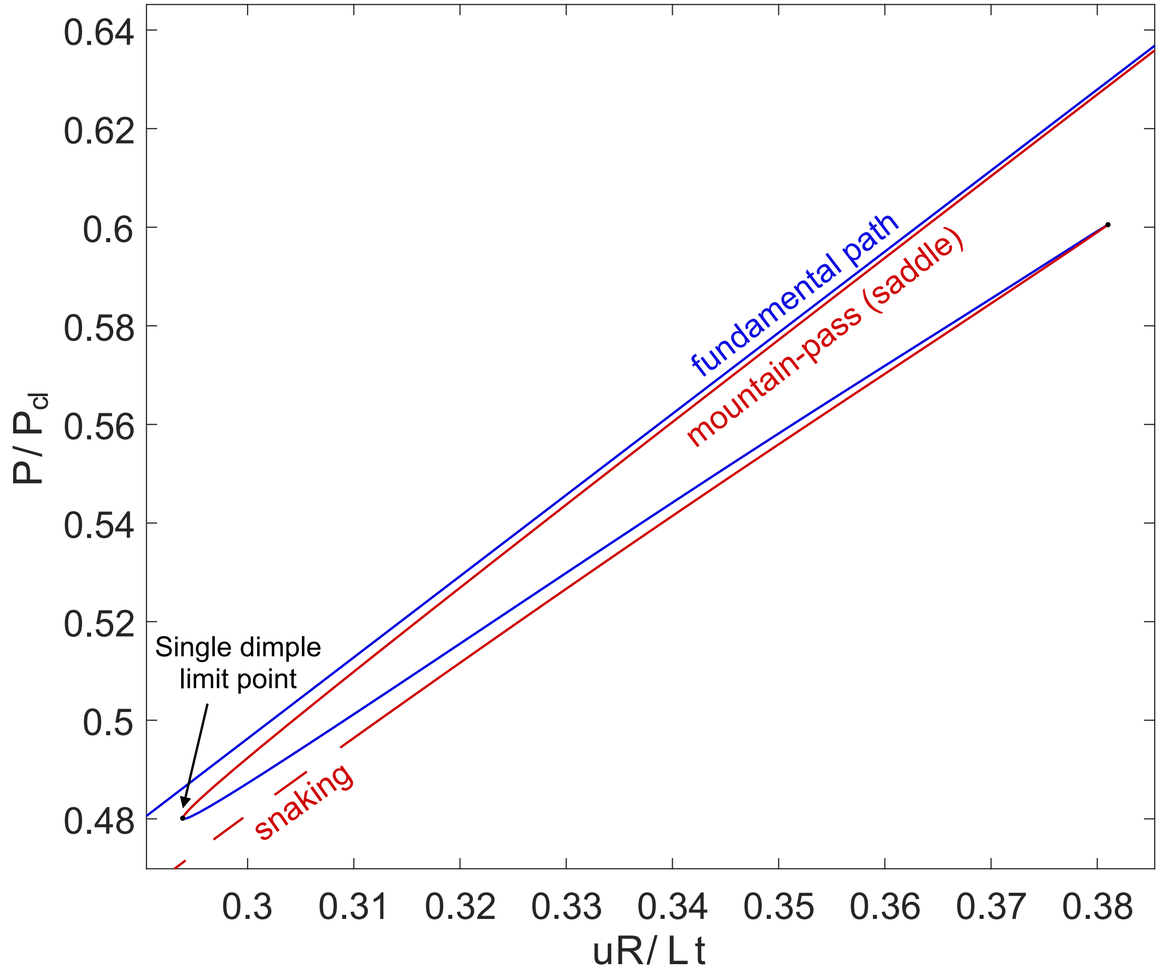
Yoshimura-like deep post-buckling pattern



Single-dimple Tracking

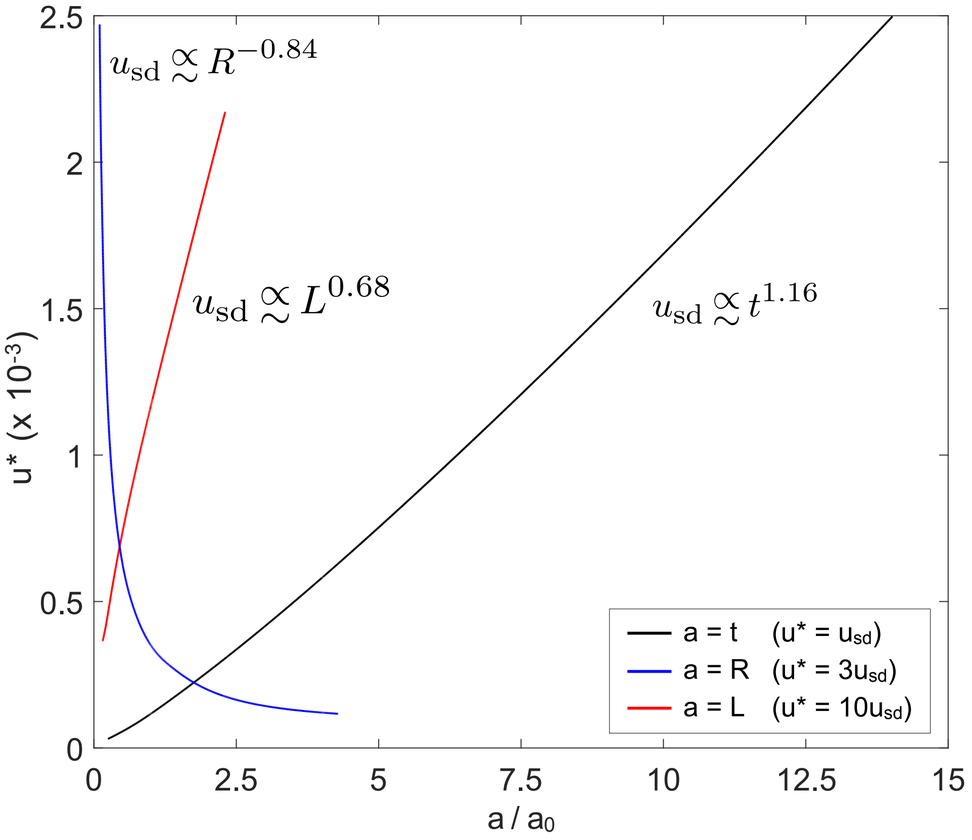
- From pre-buckling to stable diamond pattern via the single dimple
- When is the single dimple an unstable saddle?
- Use bifurcation tracking capability





Single-Dimple Threshold

$R^2 > 0.995$ in all cases

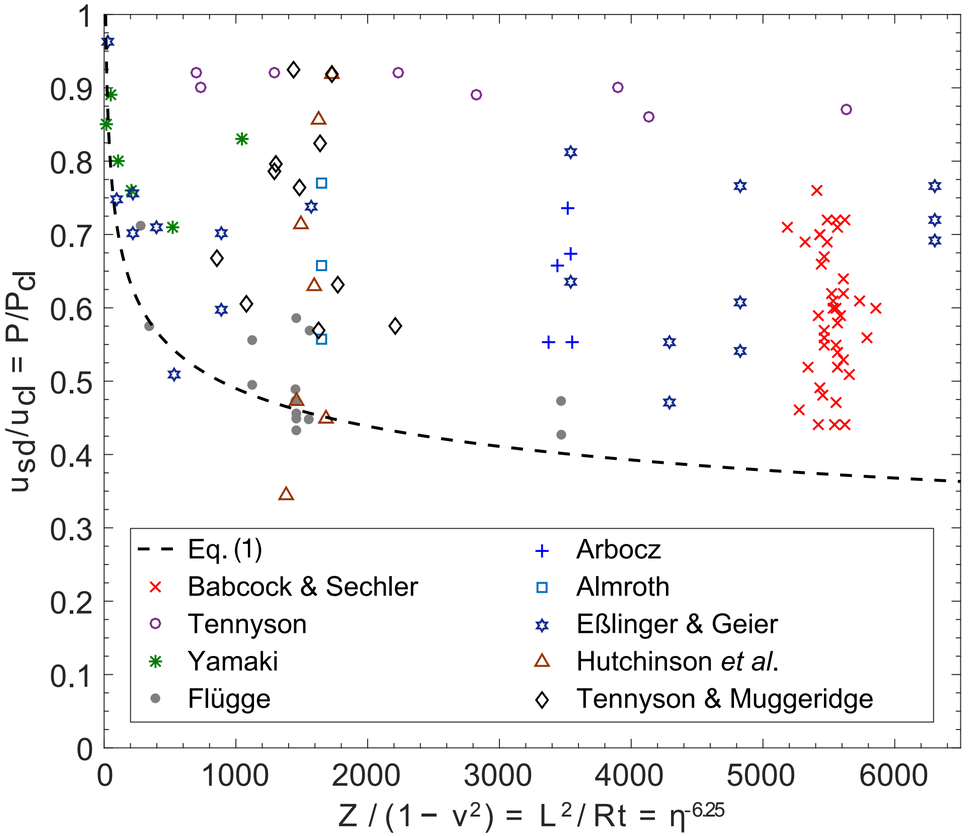


Single-dimple curve is a function of the Batdorf parameter

$$\frac{P}{P_{cl}} = 1.48\frac{R^{0.16}t^{0.16}}{L^{0.32}} = 1.48\eta$$

$$Z/\sqrt{1-\nu^2} = L^2/Rt = \eta^{-6.25}$$

115 experimental results



Comments

- Outlier by Hutchinson *et al. (*1971*)* is an axisymmetric dimple with relatively large amplitude
- Also, many data points from NASA SP-8007 exist below single-dimple curve, *e.g.* Donnell (1934)
- Asymptote NASA: $P/P_{cl} \sim 0.2$ and SD: $P/P_{cl} \sim 0.35$
  - previous manufacturing technology less controlled
- ➔ Buckling below the threshold is possible, but not likely with modern engineering process control
- ➔ Less conservative design guideline than NASA SP-8007 for cylinders manufactured to tight dimensional control

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Thank you for your attention!

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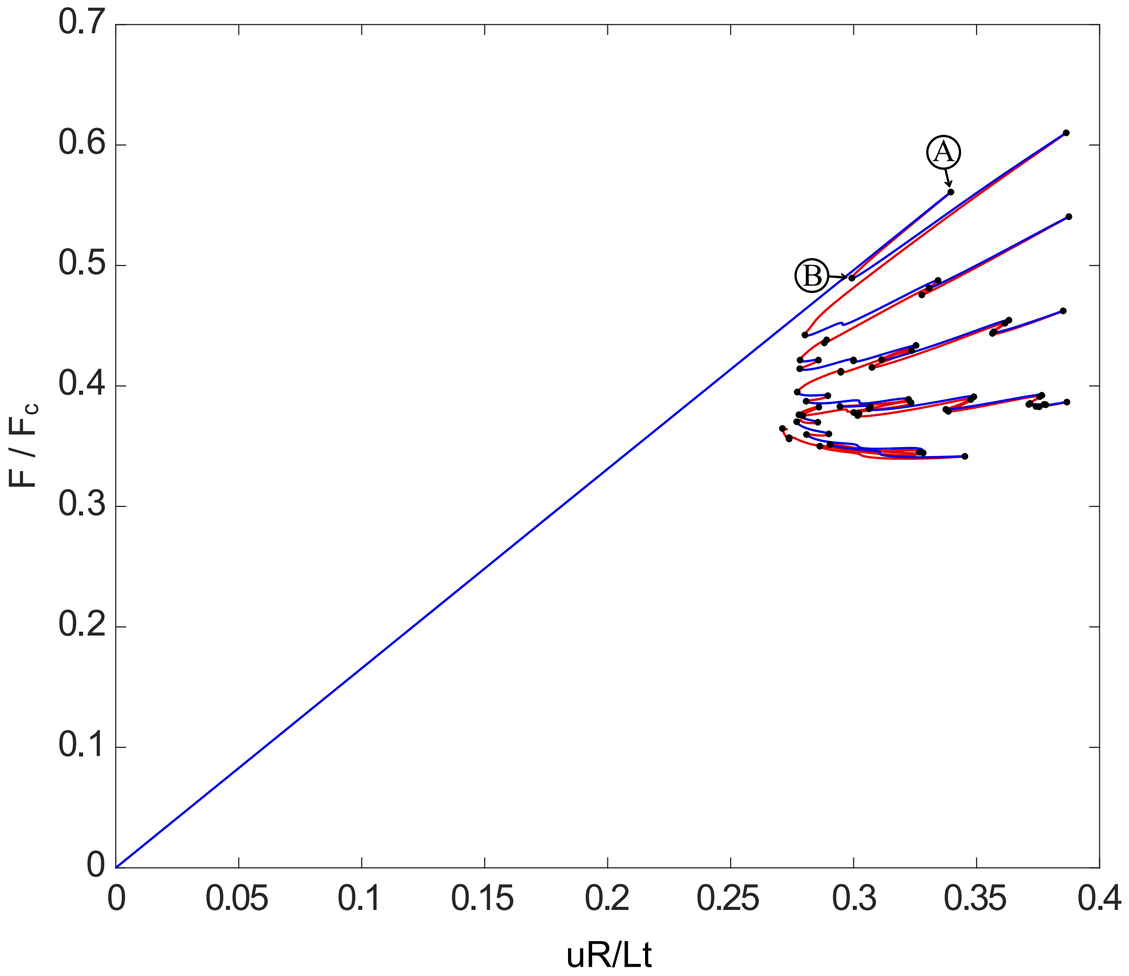
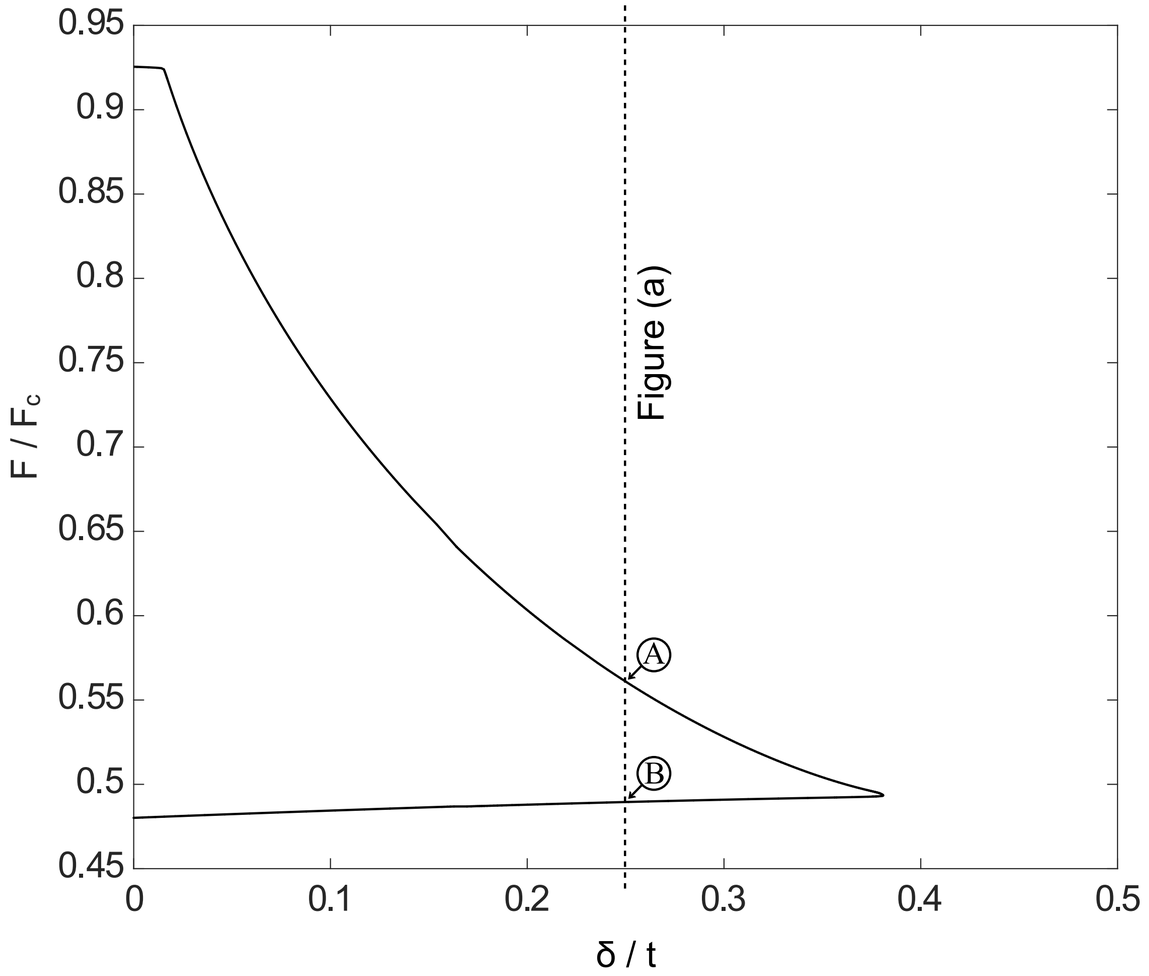
Single-Dimple Imperfections



(a)



(b)